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Assessment of environmental sustainability of technologies using Life Cycle Analysis

Corominas, Lluis; Flores-Alsina, Xavier; Vanrolleghem, Peter A.; Larsen, Henrik Fred; Joss, Adriano; Siegrist, Hansruedi

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Neptune FP6 Project – Assessment of environmental sustainability of technologies using Life Cycle Analysis

Lluís Corominas[1)], X. Flores-Alsina[1)], P.A. Vanrolleghem[1)], H.F Larsen[2)], A. Joss[3)] and H. Siegrist[3)]

[1)] model*EAU*, Université Laval, Canada

[2)] Technical University of Denmark

[3)] EAWAG, Switzerland

modelEAU DTU eawag aquatic research International Water Association

2nd IWA/WEF Wastewater Treatment Modelling Seminar
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Water Environment Federation® Preserving & Enhancing the Global Water Environment

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- Experimental example
  (Separate sludge liquor treatment)
- Modeling example
  (use of control to reduce GHGs)
- Conclusions

Introduction (general scope for Neptune)

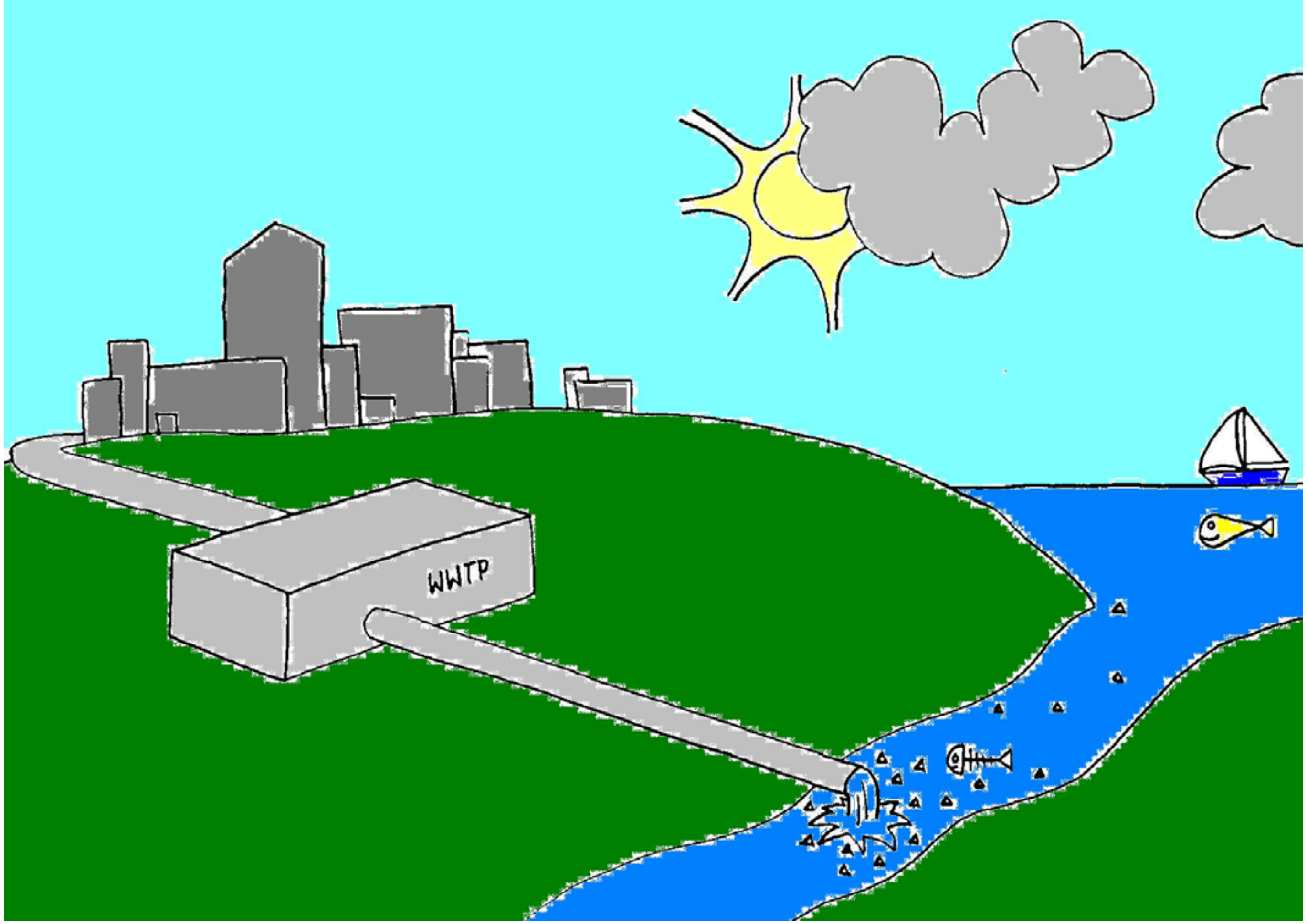
- The scope of sewage treatment is changing
- WWTP are delivering resources to the environment and for the human activities

Existing focus:		**New focus**:
● Wastewater treatment	⇨	Water reuse
● Nutrient removal	⇨	Nutrient recycling
● Pathogens removal	⇨	Micropollutants and ecotoxicity removal
● Energy optimization	⇨	Energy production
● Sludge disposal	⇨	Reuse of sludge and of its resources

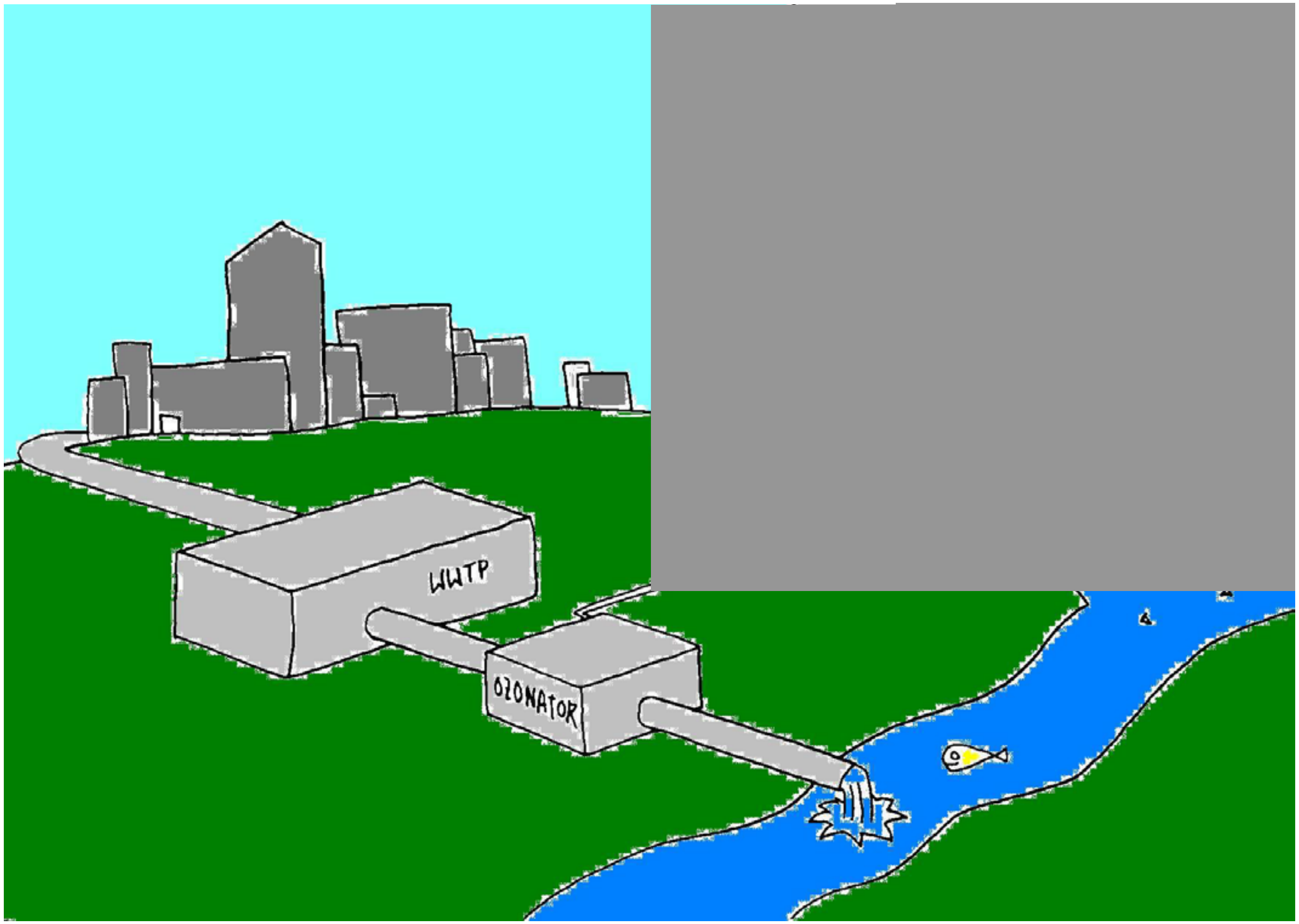
This shift has implications on the quality goals for WWTP products.

Neptune
FP6 Project

Introduction (LCA methodology)



Introduction (LCA methodology)



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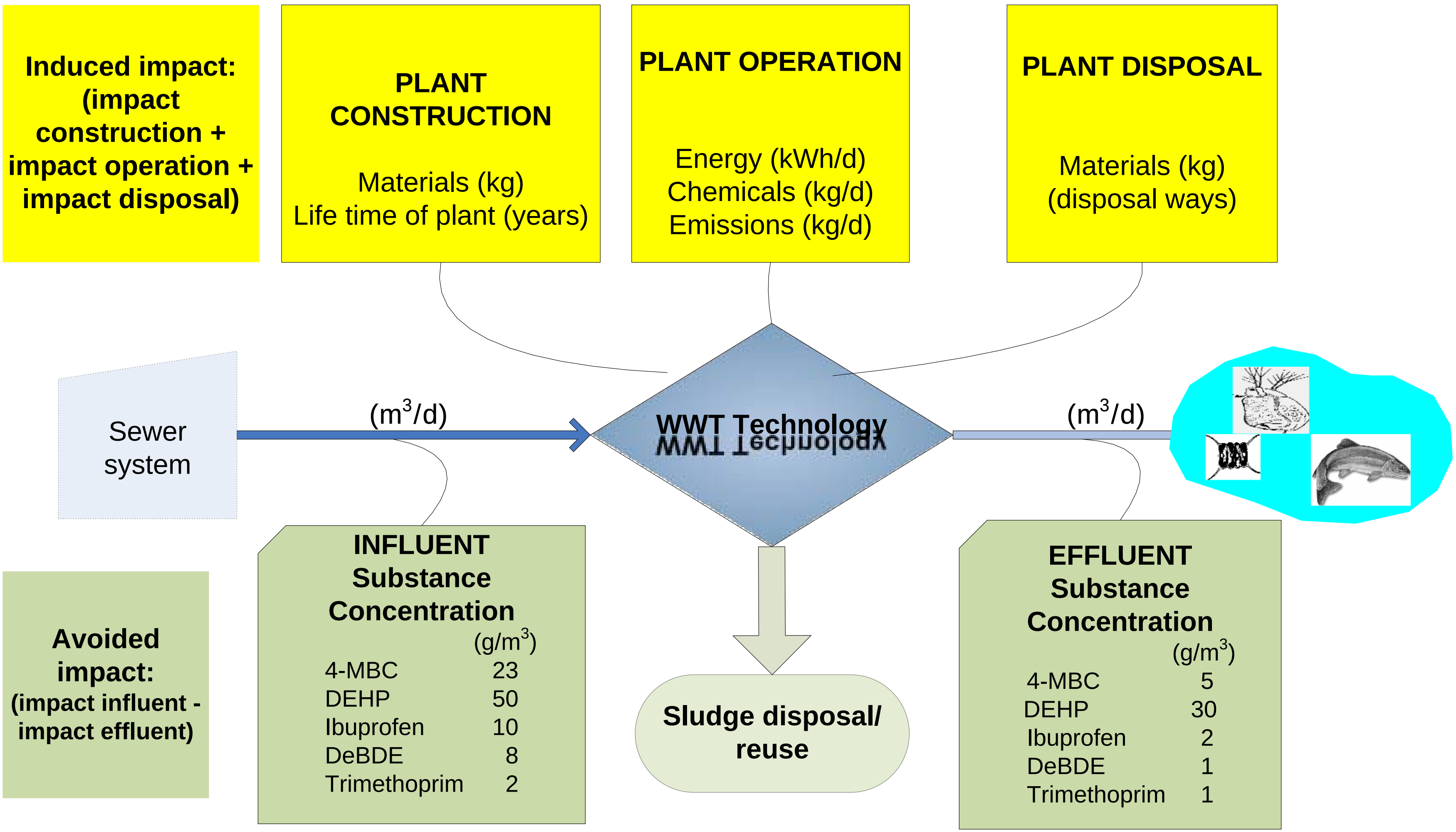

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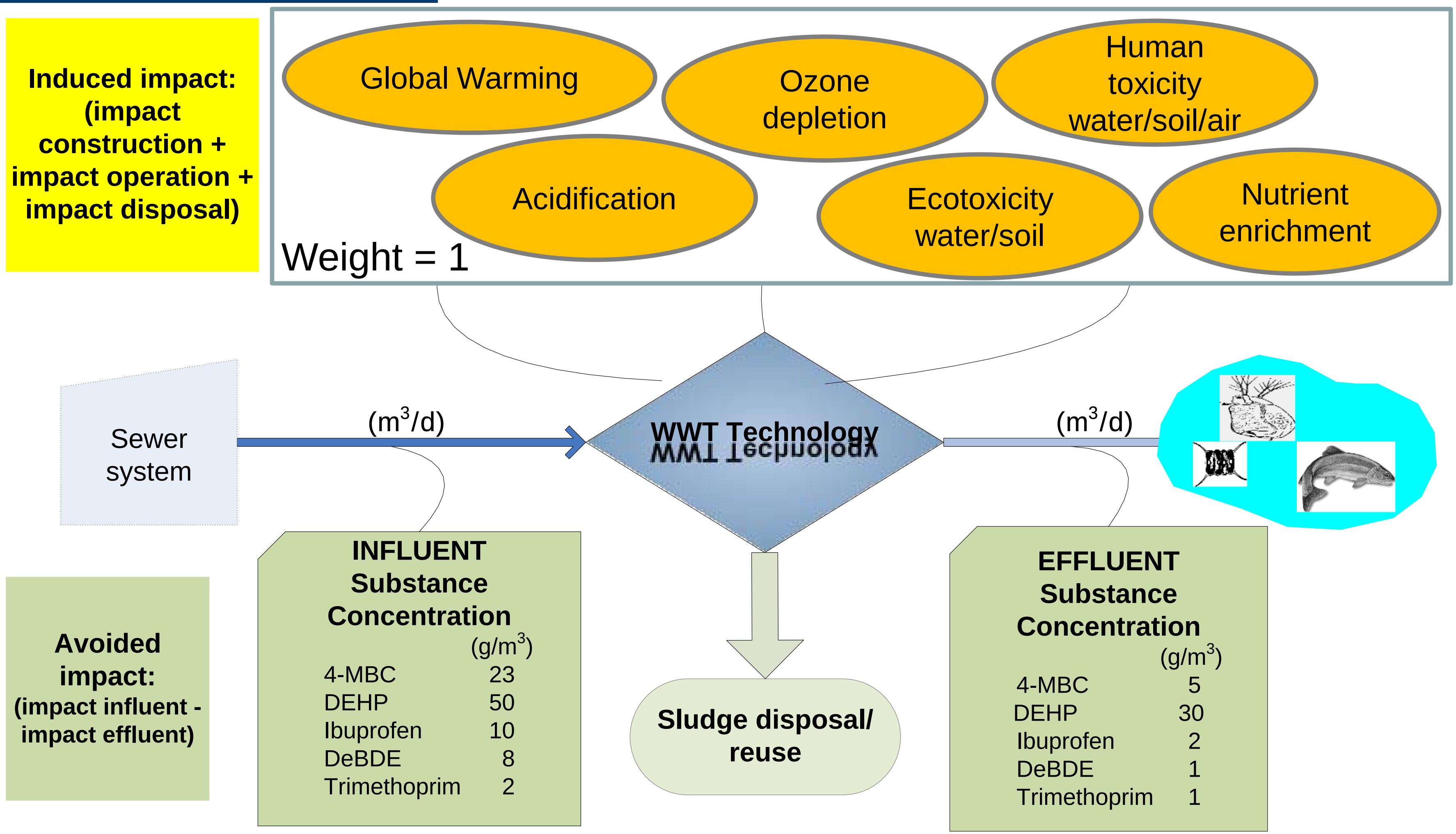


2. LCA to evaluate control

Variables and impact factors

Variables (var)	Impact factors (mPET*year/unit) WF=1
Nitrogen (kg N)	37.23
Phosphorus (kg P)	269.2
Electricity consumption (kWh)	0.12324
Sludge production (kg sludge, 63% water)	0.1
Infrastructure (m^3 influent treated)	0.127
External carbon source (acetate)	3.8781
Metal ($FeCl_3$, 40%)	2.6110
Micropollutant 1	X
Micropollutant 2	Y
…	…

- Functional unit (1m^3 of treated wastewater)

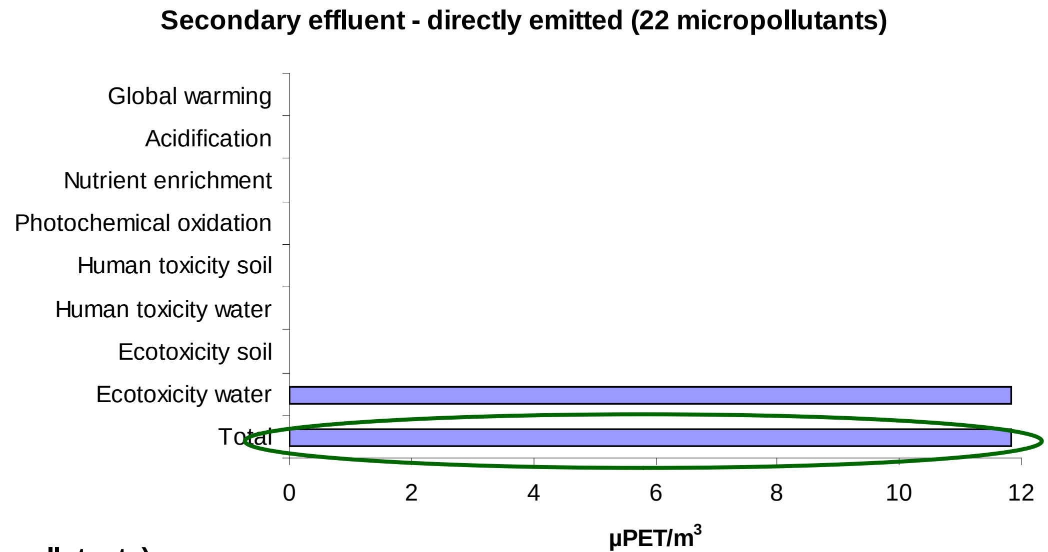
- Calculation

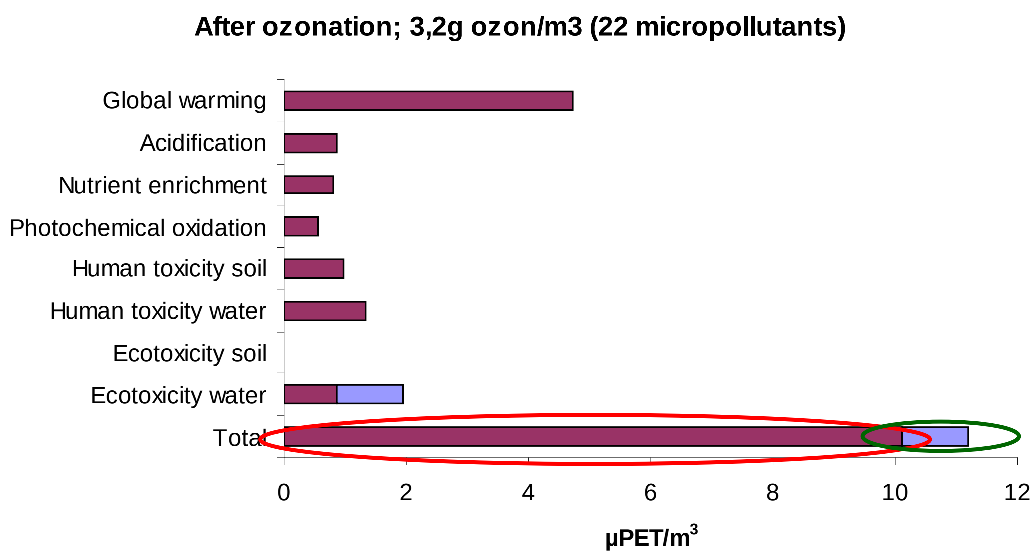
$$NIP_{(var)} = \frac{Value_{(var)} \text{ x IF}}{m^3 \text{ treated WW}} \qquad \left[mPET * year / m^3\right]$$

Introduction (LCA methodology)

LCA impact profiles

(weighting factor = 1 for all impact categories)
(non-conservative ecotox CFs)





Avoided: 10,7 µPET/m3

Induced: 10,1 µPET/m3

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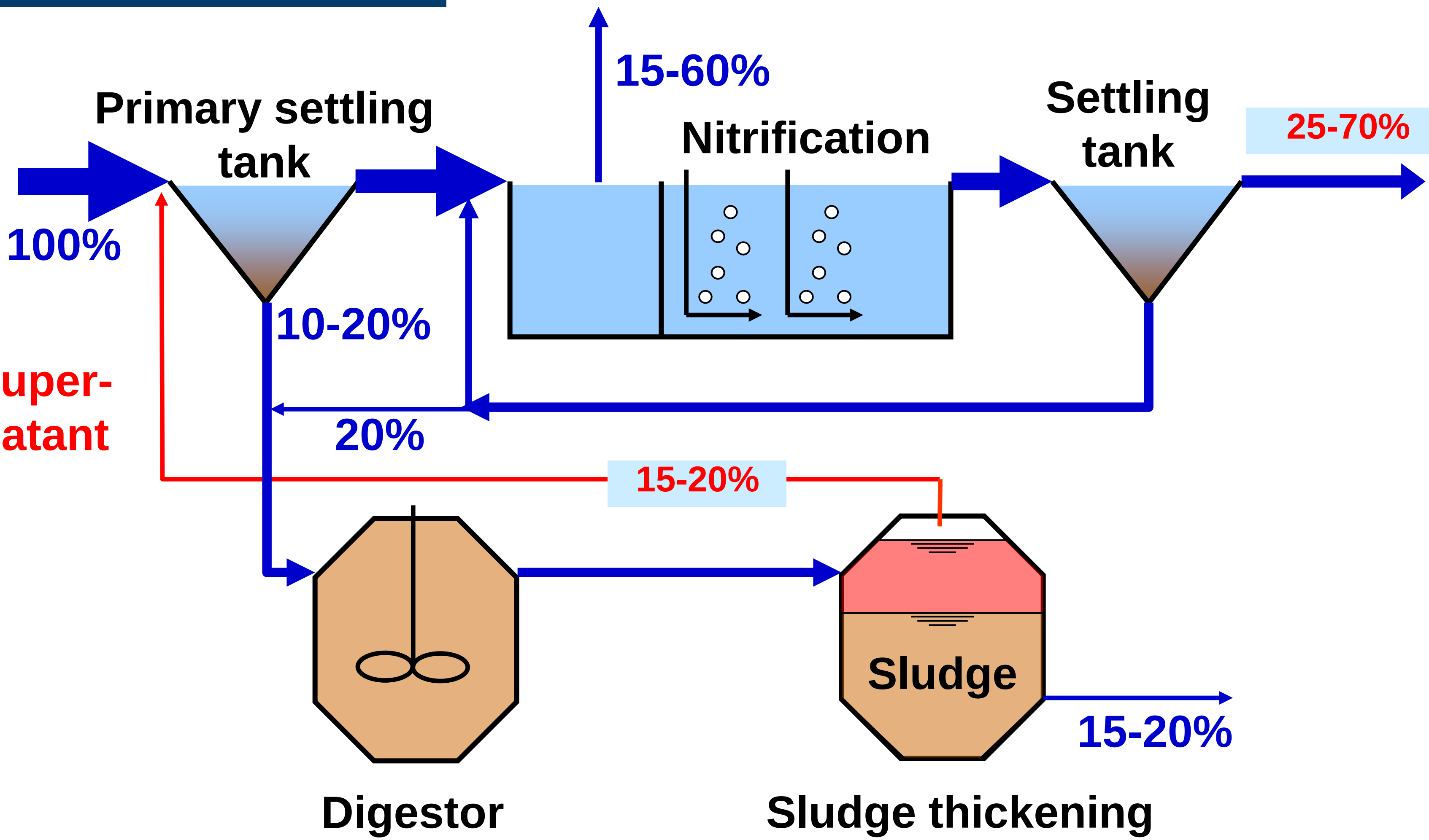
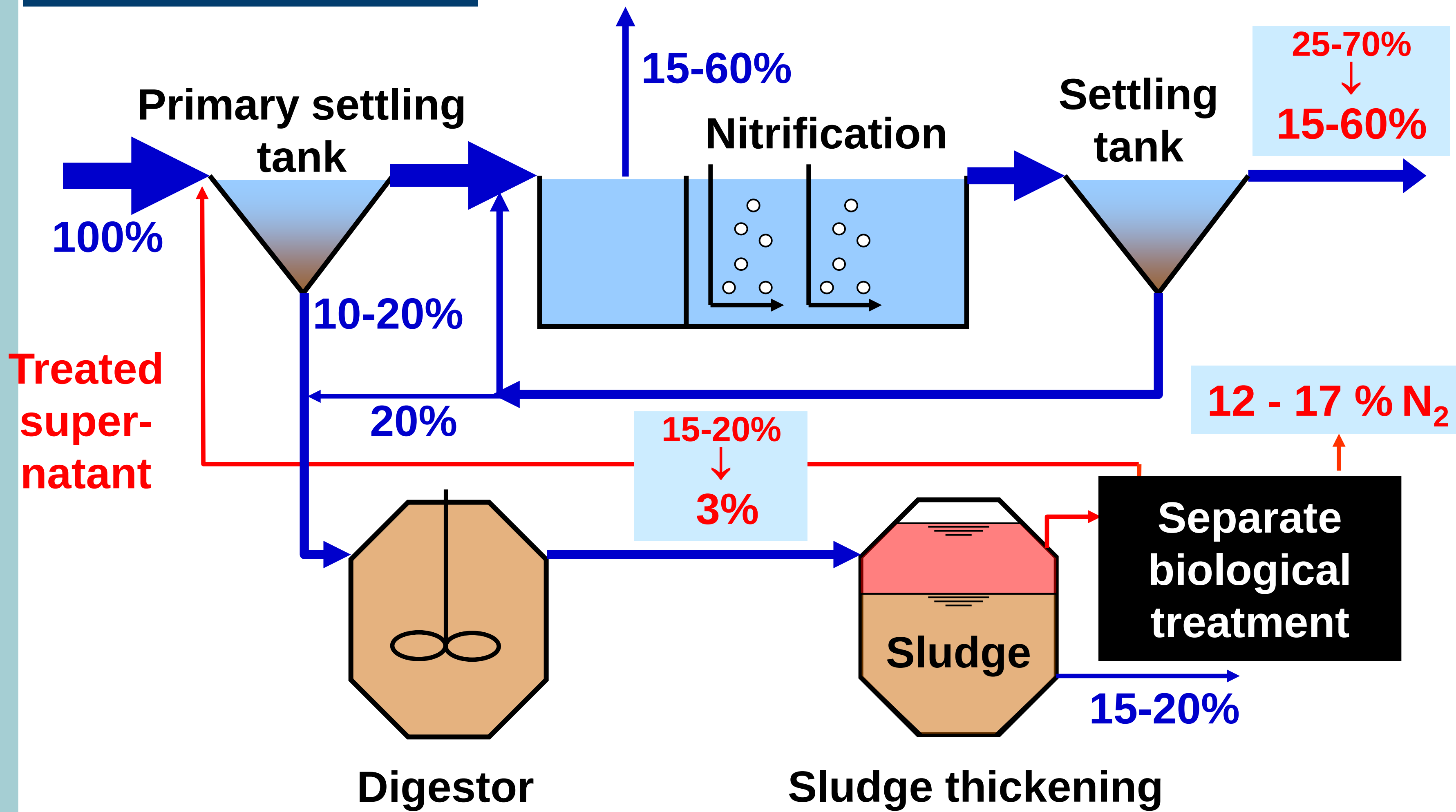
Separate sludge liquor treatment

Nitrogen fluxes in wastewater treatment



Separate sludge liquor treatment

Nitrogen fluxes in wastewater treatment



Separate sludge liquor treatment

Aeration energy:	0.7 kWh/kgO_2
Energy equivalents:	0.7 $kgCO_2/kWh_{electric}$
Methanol equivalents:	1.4 $kgCO_2/kgMeOH$
N_2O equivalents:	310 $kgCO_2/kgN_2O$

		Conventional Nitrific./Denitr.	**Combined Nitrit.-Anammox**
O_2 consumption	kgO_2 / $kg_{N\ elim}$	4.3	1.9
Aeration energy	kWh / $kg_{N\ elim}$	2.4	1.0
Aeration (CO_2 equiv.)	$kgCO_2$ / $kg_{N\ elim}$	**1.4**	**0.6**
Carbon source	kg_{MeOH} / $kg_{N\ elim}$	2.2	-
Carbon source (CO_2 equ)	$kgCO_2$ / $kg_{N\ elim}$	**3.1**	**-**
N_2O production	gN_2O / $kg_{N\ elim}$	0.1 to 17[+]	4[°°]
N_2O production (CO_2 equ)	$kgCO_2$ / $kg_{N\ elim}$	**0 to 5.3**	**1.2**
Total CO_2 equivalents	**$kgCO_2$ / $kg_{N\ elim}$**	**4.5 to 10**	**1.8**

[+] Katrik Chandran, personal communication, 2010

°° Joss et al. 2009, Environ. Sci. Technol.

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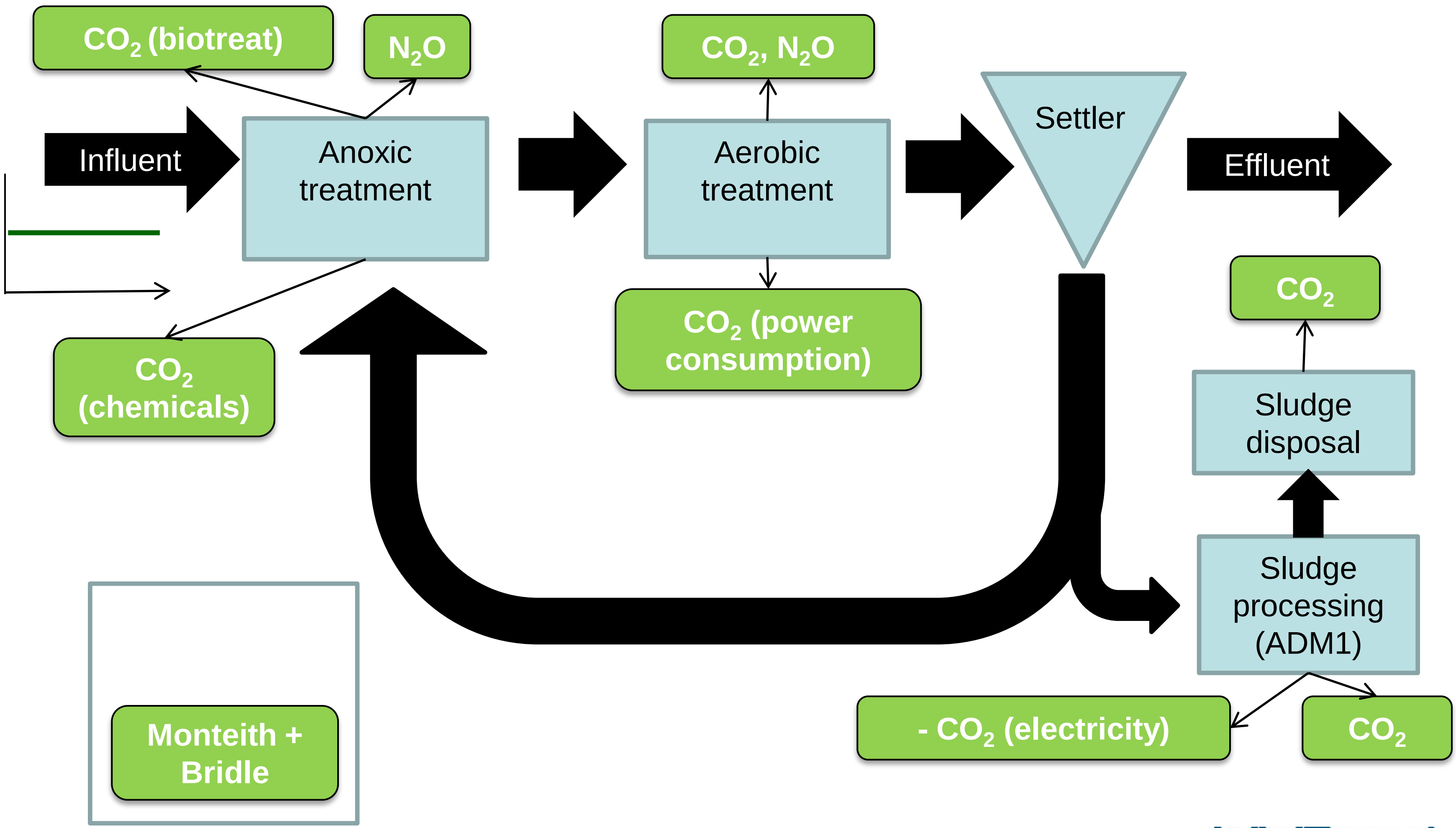
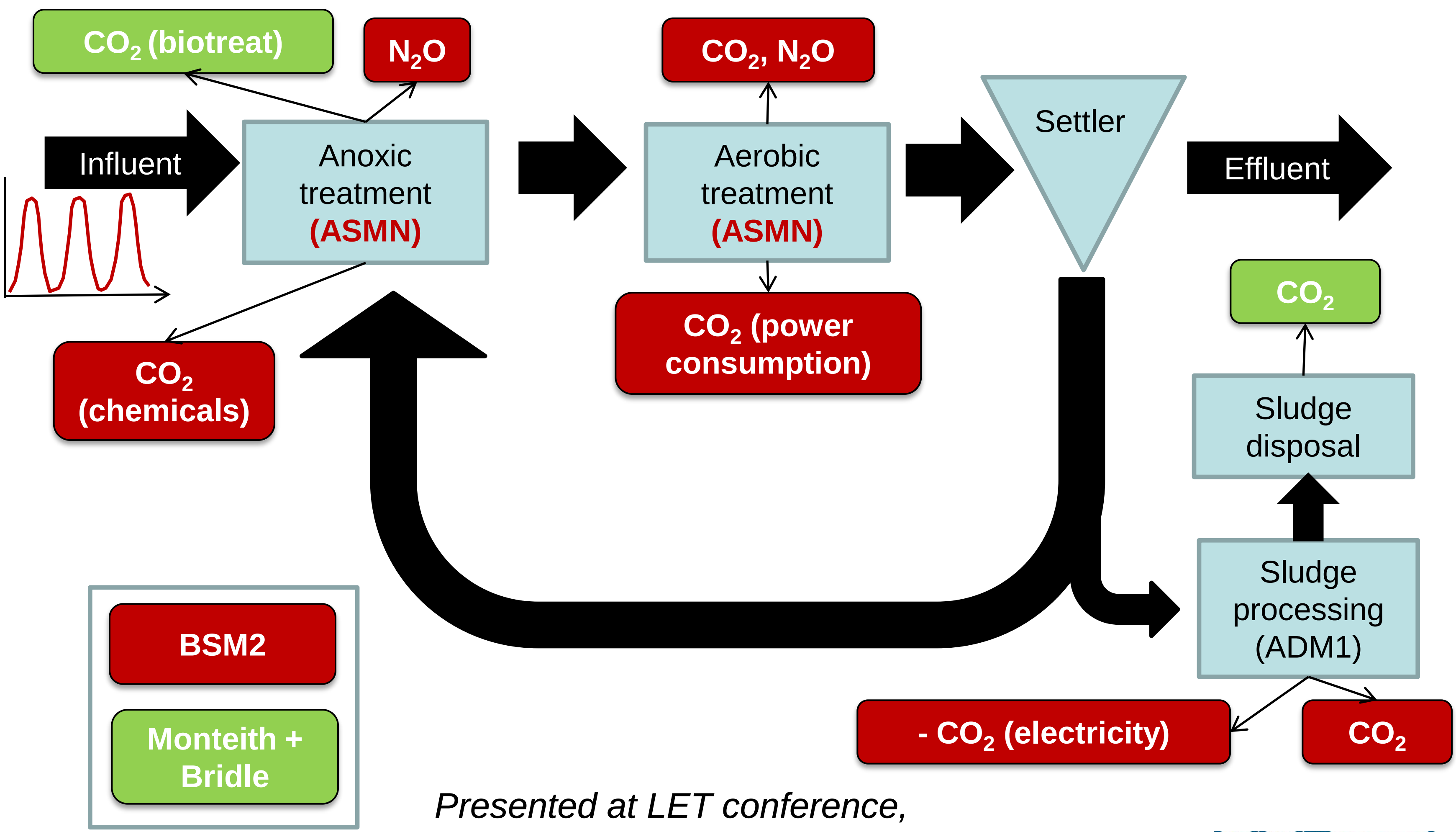
Modeling example (Steady state)



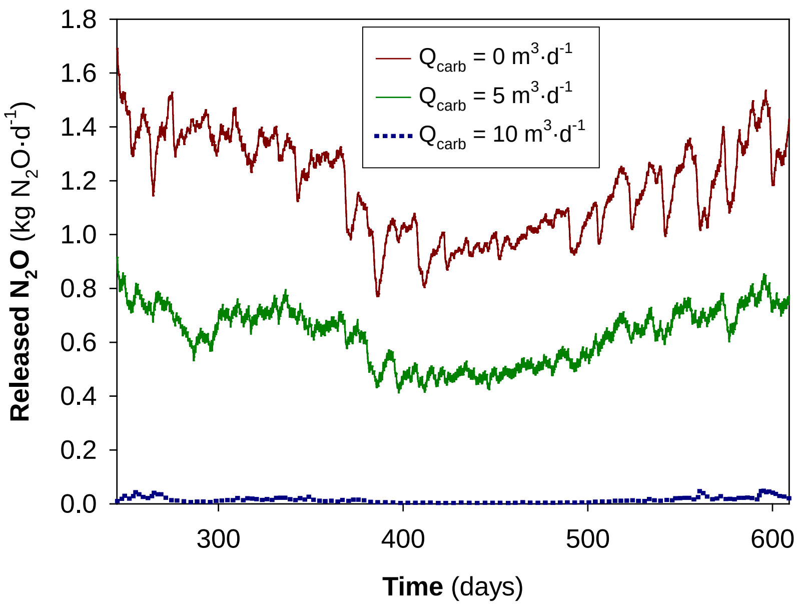
Modeling example (Dynamic)

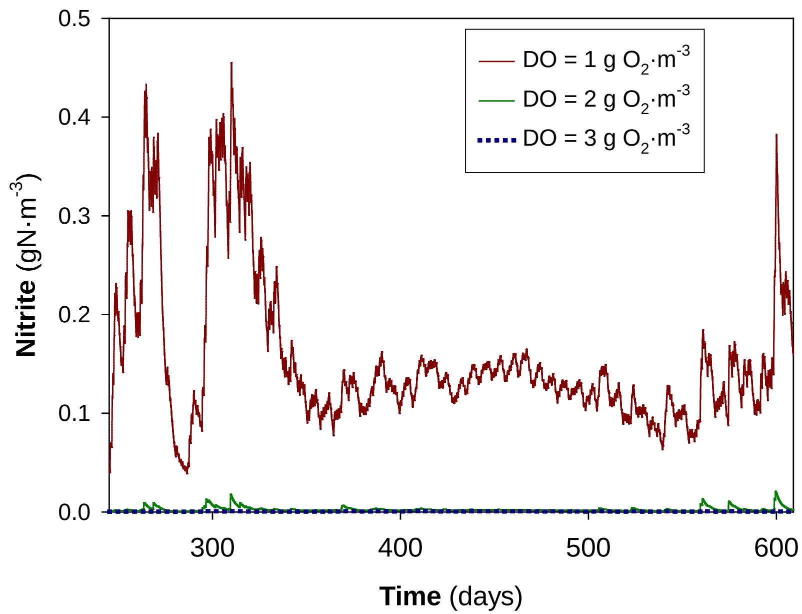


Presented at LET conference, June 2010 (Phoenix)

Modeling example (Dynamic results)

- Dynamic profiles from the model
- Dynamics needed to study control options
- Different N_2O results for steady-state and dynamic simulations





Modeling example (results)

- Comparsion of ***open-loop*** and ***closed-loop*** (DO control in aerobic reactor)

	Open Loop	**Closed Loop**	**%**
Effluent Quality, EQI (kg poll·d^{-1})	6461	6181	-4
Costs, OCI (-)	14107	13254	-6
GHG emissions (kg CO_2e·m^{-3}**)**	0.975	0.860	-12

$$EQI = \frac{1}{t.1000}\int_{to}^{tf}(PU_{TSS} + PU_{BOD} + PU_{COD} + PU_{TKN} + PU_{NO} + PU_{TP})\cdot Q\cdot dt$$

OCI = Sludge production + Aeration + Pumping + Mixing +

6·Carbon addition + Heating – 6·Methane production

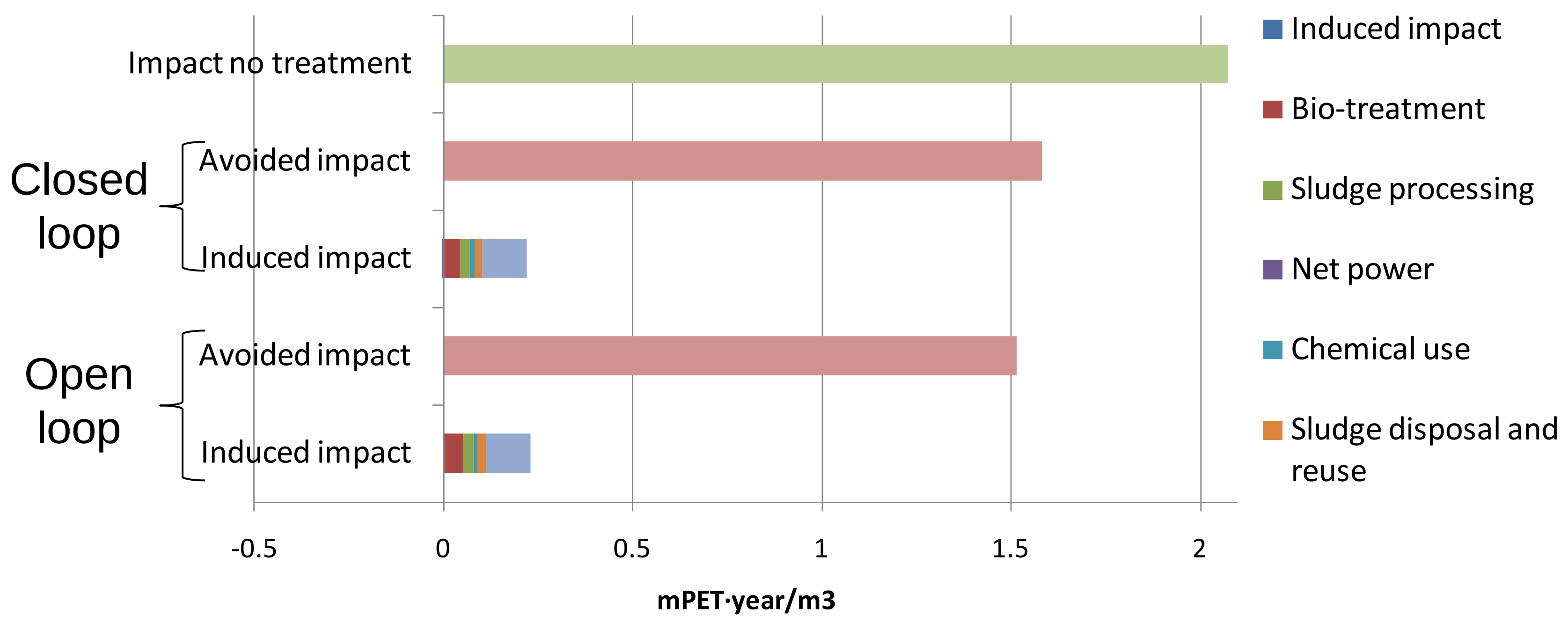
Modeling example (results)

- Comparsion of open-loop and closed-loop (DO control in aerobic reactor)

Breakdown of GHG emissions (kg $CO_2e \cdot m^{-3}$**)**	**Open Loop**	**Closed Loop**	**%**
Bio-treatment GHG emissions	**0.451**	**0.376**	-17
Biomass respiration	0.179	0.178	-1
BOD oxidation	0.212	0.212	0
Credit nitrification	-0.168	-0.167	-1
N_2O emissions	0.228	0.152	-33
Sludge processing GHG emissions	**0.231**	**0.231**	0
Net power GHG emissions	**0.000**	**-0.038**	-
Power	0.311	0.272	-13
Credit power GHG emissions	-0.311	-0.310	0
Embedded GHG emissions from chemical use	**0.099**	**0.099**	0
Sludge disposal and reuse GHG emissions	**0.193**	**0.193**	0

Modeling example (results)

- LCA results (includes construction, nutrients, power, sludge treatment, sludge disposal)



5% improvement closed loop compared to open loop

Conclusions and perspectives (I)

- LCA is useful to evaluate environmental impact
  - Higher impact for nutrient enrichment and ecotoxicity than greenhouse gases
  - Further research is needed to define weights for the different impact categories (related to policy making)

Conclusions and perspectives (II)

- GHG emissions included as a new dimension to evaluate treatment options:
  - Experimental example, Evaluation of sludge liquor treatment options:
    - Nitritation-Anammox less environmental impact than conventional systems
  - Modeling example, Evaluation of control strategies:
    - Requires deterministic dynamic models to estimate GHG emissions
    - Further research needed to compare different GHG estimation methods

Acknowledgements

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Canada Research Chair in Water Quality Modeling